Preliminary Analysis
MSc Ocean Physics, University of Victoria

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Contents

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1 Analysis

- *add more description of project, here*
  All plots and analyses are works-in-progress, and are only samples to highlight the potential of this research. Preliminary analysis has been carried out using ONC Oceans 2.0 for data acquisition, Python and Jupyter Notebook for data processing, LaTeX and BibDesk for document creation, and GitHub (kurtisanstey/project) for file hosting. Other relevant packages and resources are mentioned when necessary. Details can be found in the relevant Jupyter Notebook project files, hosted on GitHub.

1.1 Horizontal velocities

Velocity data were depth truncated to eliminate poor quality data near to the extreme upper and lower depth limits of each instrument. Data were interpolated over time to account for short gaps in the time series (¡ 1 day). When necessary, datasets were split around large data gaps and relevant portions pieced together (with appropriate averaging and weighting). Data were filtered to highlight differences in the mean currents and tides, by applying a 5th order 40-hour digital low-pass Butterworth filter, and examining the low-pass versus the super-inertial data. Data were rotated using Euler's formula

$$\underline{u}_{rot} = \underline{u}e^{-i\theta}$$

to better match the cross-slope angle of approximately +30°, to help identify relationships between the predominant currents and local canyon topography; u is referred to as 'cross-slope', and v is 'along-slope'.

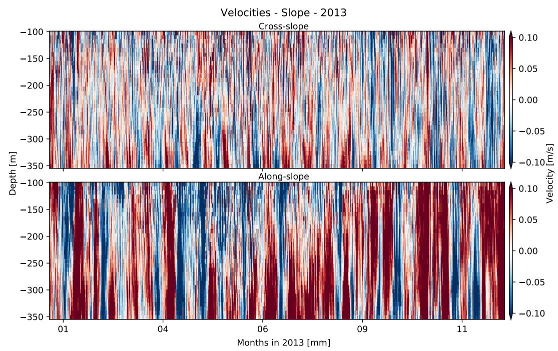
Upper Slope 75 kHz ADCP

- There are similarities in mean currents to the A1 data (Thomson), as part of the Northeast Pacific Coastal Current. Annually, there is a general semi-annual switch in the direction of the mean currents; the winter and fall appear to be dominated by the California current moving towards the northwest, and in the spring and summer, the Alaska current moving to the southeast could indicate enhanced canyon upwelling (Allen). The spring switch seems to happen quite suddenly in May/June of each year, through depth, while the switch back is a more gradual process that starts deep almost immediately and takes about three months to reach the surface at the end of the summer. There may also be indications of the Vancouver Island Coastal Current, to be identified.
- Velocities are dominant in the along-slope direction, throughout the year, in contrast to the Axis ADCP.
- Residual data shows consistent tidal influence, and do not change much throughout the years.
- Seasonally, there are apparent two week (an average estimate) pulses in mean current velocity data in the along-slope direction. There is a similar two week periodicity present in the spectrograms. This could be indicative of the spring/neap cycle. However, this periodicity does change seasonally, being somewhat slower (approaching a monthly switch) and more prominent in winter/fall, nearly entirely absent in the spring, and seemingly more sporadic or even weekly in the summer. This suggests some interaction with the more general semi-annual switching of mean currents, as described above.

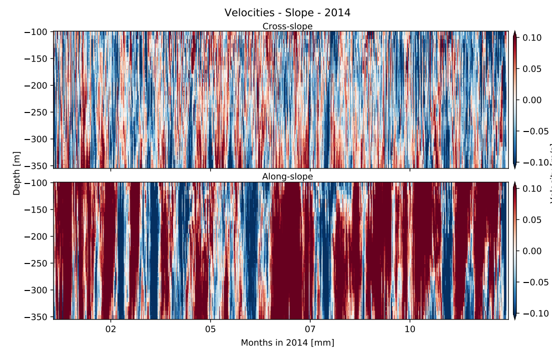
Axis 75 & 55 kHz ADCP

- Mean current velocities are slightly dominant in the cross-slope direction, throughout the year, in contrast to the Upper Slope ADCP.
- There is less seasonality to the mean current velocity data than for the Upper Slope ADCP, though there is some strengthening to the cross-slope in spring and summer at upper depths.
- Cross-slope data shows consistent flow into the canyon (onshore) at lower depths, and flow out of the canyon (offshore) at higher depths. Represents circulation within the canyon. To be confirmed.
- Along-slope data is fairly consistent towards the northwest throughout the year, with possible ∼weekly periodicity at higher depths.
- Residual data shows a consistent periodicity throughout the year, varying with depth.
- Lower depth velocity data is fairly consistent in each season.
- Upper depth velocity data is fairly consistent for along-slope, but there is winter and spring intensification for cross-slope.

1.1.1 Annual velocities



(a) 2013



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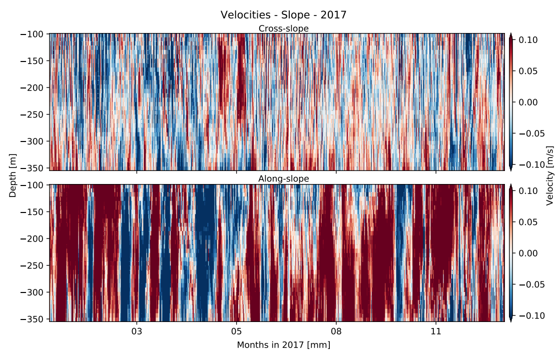

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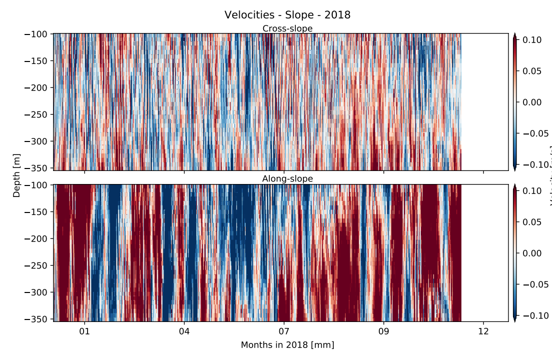
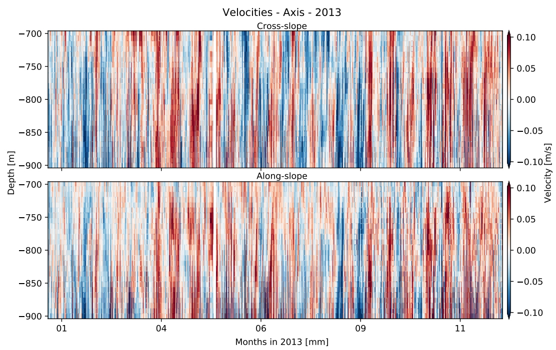
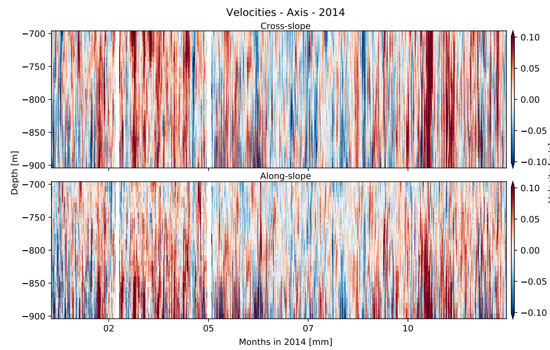


(d) 2018

Figure 1: Comparative velocity data for Upper Slope 75 kHz ADCP, in 2013, 2014, 2017, and 2018. Velocities are displayed horizontally in cross- (left) and along-slope (right) directions, and vertically as unfiltered (top), low-pass (middle), and residual (bottom) data. The 15-minute resolution velocity data has been cleaned to account for NaN gaps, extreme depth interference, and rotated to match the continental slope angle of approximately 30°west of true.



(a) 2013



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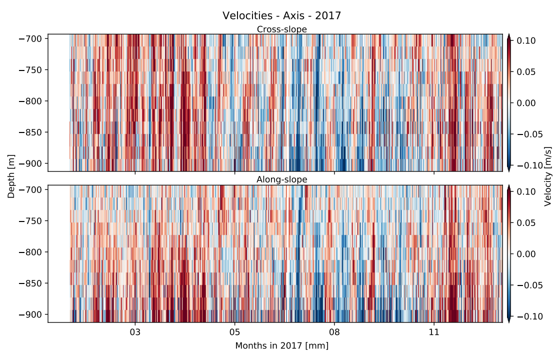

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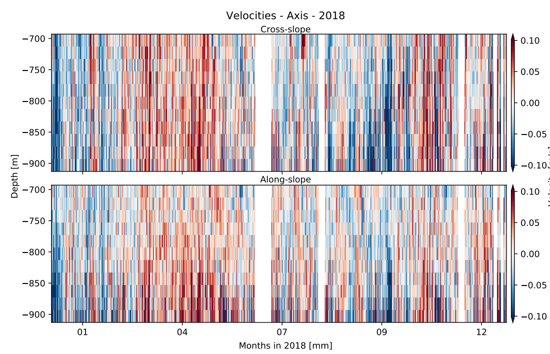


(d) 2018

Figure 2: Comparative velocity data for Axis 75 & 55 kHz ADCP, in 2013, 2014, 2017, and 2018. Velocities are displayed horizontally in cross- (left) and along-slope (right) directions, and vertically as unfiltered (top), low-pass (middle), and residual (bottom) data. The 15-minute resolution velocity data has been cleaned to account for NaN gaps, extreme depth interference, and rotated to match the continental slope angle of approximately 30°west of true.

1.2 Annual PSD

Power spectral density (PSD) plots were created from rotated, cleaned, and mean removed velocity data. A Welch method FFT process was used, with averaging parameters set according to the length of each data set (8-10 day windows for an annual set), and a 15-minute sampling rate for ideal smoothing of spectral features. For reference, also plotted are notable frequency constituents, 95% confidence intervals calculated using a chi^2 routine, and expected continuum slopes from the GM79 theory. The noise floor for each instrument is determined from standard error of the mean, based on the standard deviation, pings, ensemble time, and temporal averaging for each dataset. Specific depths were selected as the upper and lower extrema of depth values obtained by each ADCP, after being truncated to remove poor quality data (see Velocity section).

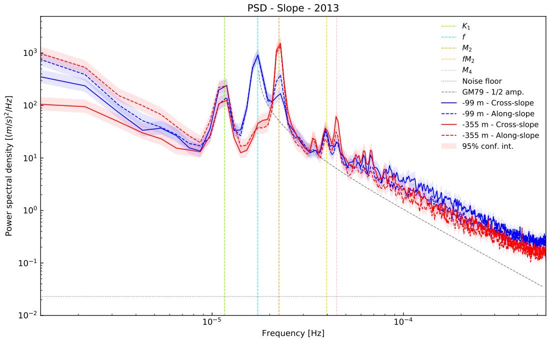
The classical GM spectrum for this region was generated from buoyancy data from seasonal CTD casts by Fisheries and Oceans Canada (DFO), at Line P Station P4, about 27 km from Barkley Canyon. An annually averaged buoyancy frequency of about 3.33e-3 rad/s, local Coriolis frequency of about 1.09e-4 rad/s, and standard GM parameters as described in theory.

Upper Slope 75 kHz ADCP

- Cross/Along-slope spectra have comparable variance and features at both depths, and through each observed year.
- f and M_2 dominate at upper depth, as expected near canyon topography. f is weaker in deeper waters, and M_2 is stronger. $K1$ is significant, but lesser.
- There appear to be sum peaks for fM_2 and M_4, as discussed by Mihaly/Thomson. By their reasoning, this *could* indicate non-linear wave-wave interaction as a means of energy decay for internal waves, due to downward wind internal waves and upward topographic internal tides. They predict winter intensification (see Seasonal PSD)..
- As an annual PSD, there are no notable high frequency peaks beyond M4, at this resolution.
- In all cases, the continuum above M2 shows higher variance than expected by GM theory, potentially indicating high frequency events.

Axis 75 & 55 kHz ADCP

- In the early years (75 kHz instrument) there is far greater variance (unusually so) in the cross-slope upper depth, and both directions show unusually repetitive peaks. This could be an instrument issue. Most analysis will be for the later years (55 kHz instrument).
- There is a 'flattening' of the continuum slope in later years (55 kHz instrument), that could be the noise floor.
- Later, $M2$ dominates at the upper depth (-393 m) and both $K1$ and $M2$ are present near the bottom, possibly due to turbulent effects amplifying primary constituents.
- $fM2$ and $M4$ are present in later years (see annual).
- The later years, the continuum variance is somewhat higher than the GM theory would suggest near bottom, and somewhat lower near the canyon lip, until the possible noise floor kicks in.



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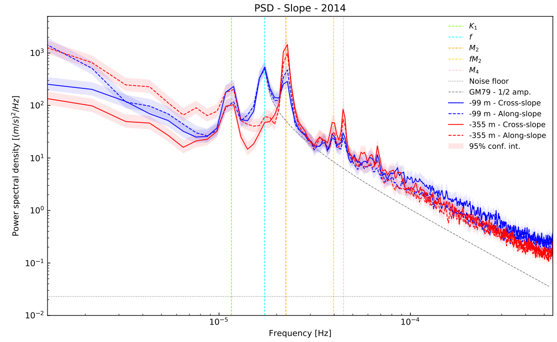

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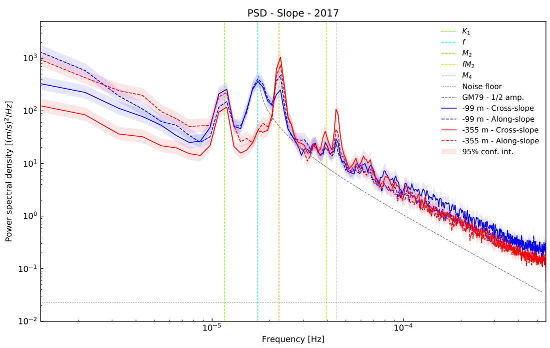

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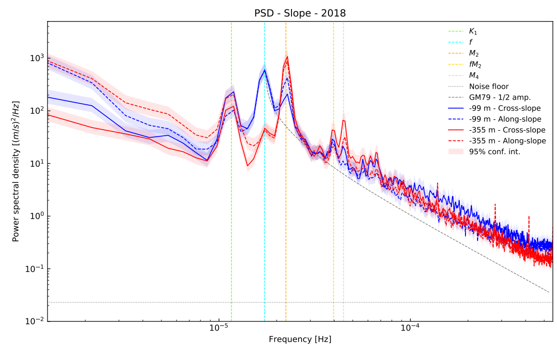
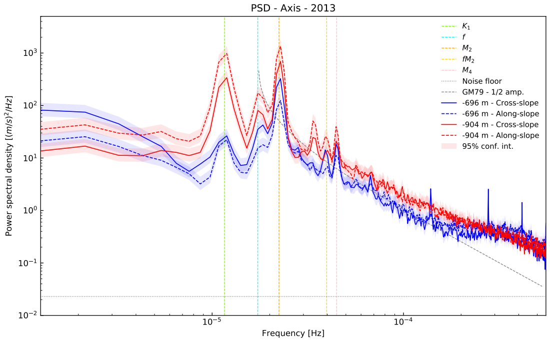
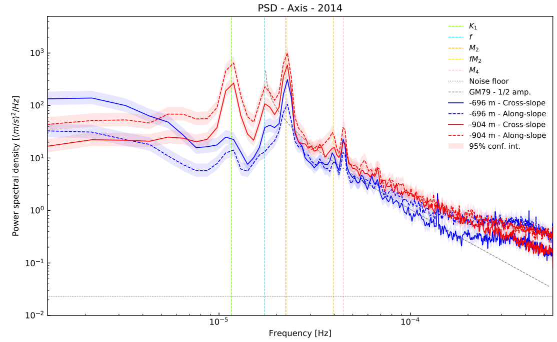


(d) 2018

Figure 3: Comparative annual PSD data for Upper Slope 75 kHz ADCP, in 2013, 2014, 2017, and 2018. PSD are for the cross- and along-slope velocity data, at an upper depth of -99 m and lower depth of -330 m. PSD were processed using mean-removed and cleaned velocity data (see above), and optimised Welch FFT parameters.



(a) 2013



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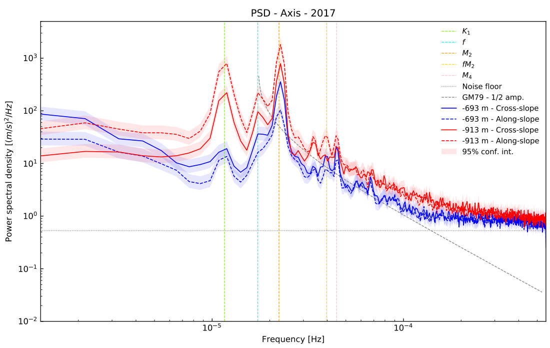

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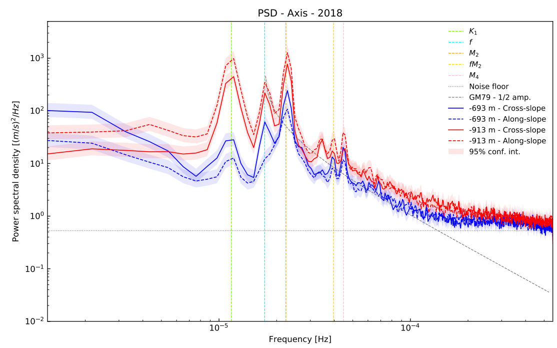


(d) 2018

Figure 4: Comparative annual PSD data for Axis 75 & 55 kHz ADCP, in 2013, 2014, 2017, and 2018. PSD are for the cross- and along-slope velocity data, at an upper depth of -99 m and lower depth of -330 m. PSD were processed using mean-removed and cleaned velocity data (see above), and optimised Welch FFT parameters.

1.3 Annual rotary

Rotary spectra were created from similar data as for PSD, and a custom process was based on the work of Thomson (2014) and Gonella (1972) to determine CW and CCW components, and better inspect inertial/near-inertial contributions. Additional rotary analysis plots will be developed in 2D for time and depth, after 1D analysis has been properly calibrated.

The classical GM spectrum was modified for it's rotary components with a custom process based on Thomson, Gonella, Levine, and Polzin, and a consistency relation for rotary energy of

$$\frac{CCW}{CW} = (\frac{\omega - f}{\omega + f})^2$$

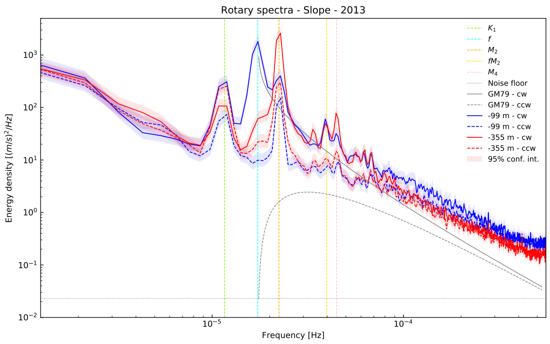
.

Upper Slope 75 kHz ADCP

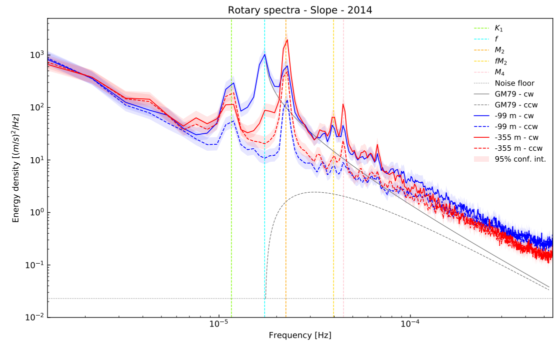
- Overall variance is comparable for both Slope depths.
- Variance is higher for CW motions, as expected in the northern hemisphere. f is reduced for CCW motions.
- f has a strong signal near the surface, CW, while in all other cases M2 is the dominant constituent. K1 also has a significant peak, though it is less.
- In all cases, the continuum higher than M2 exceeds the expected GM variance for deep water at this latitude, indicating potential high-frequency events.

Axis 75 & 55 kHz ADCP

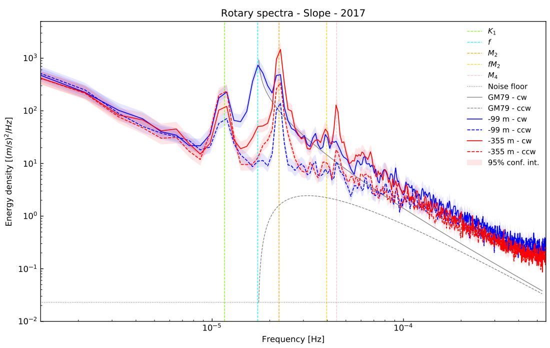
- The 75 kHz instrument (2013 and 2014) shows odd spikes at the upper depth, and unusually high variance, that may be a beam issue. The lower depths seem OK.
- The 55 kHz instrument (2017 and 2018) has a notable 'flattening/whitening' of the high frequencies that may be the instrument noise floor.
- Overall variance for -913 m is similar in all cases, and -400 m is similar only for each instrument (K1 dominates for the 75 kHz instrument, and M2 for the 55 kHz).
- The inertial frequency peak is lessened at these depths, compared to Upper Slope, and is primarily a component at -400 m versus -913 m.
- In all cases, the continuum higher than M2 exceeds the expected GM variance for deep water at this latitude, indicating potential high-frequency events.



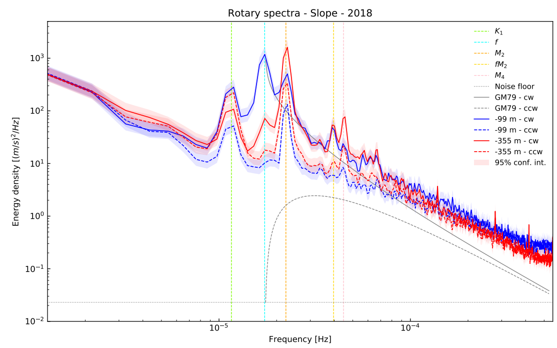
(a) 2013



(b) 2014

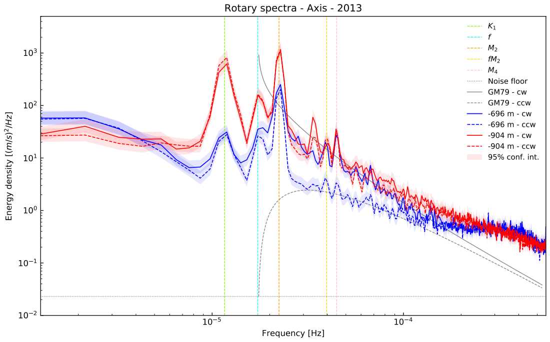


(c) 2017

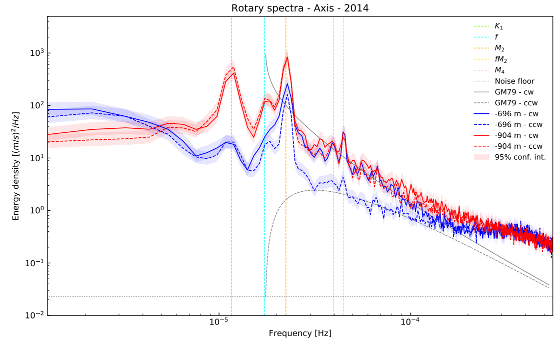


(d) 2018

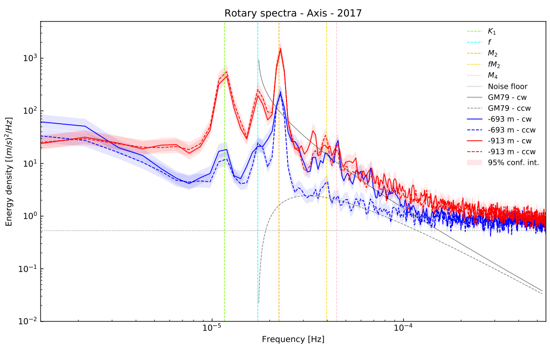
Figure 5: Comparative annual rotary data for Upper Slope 75 kHz ADCP, in 2013, 2014, 2017, and 2018. Rotary spectra are for the CW and CCW velocity data, at an upper depth of -99 m and lower depth of -330 m. PSD were processed using mean-removed and cleaned velocity data (see above), optimised Welch FFT parameters, and a custom process based on Thomson and Gonella, as described above.



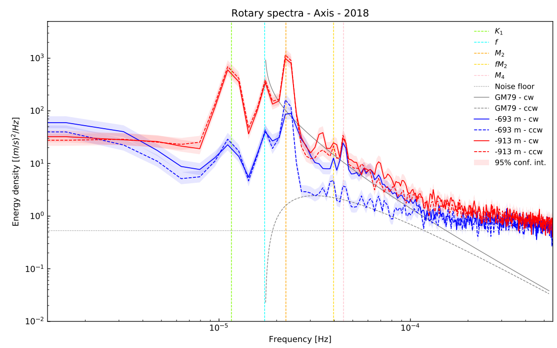
(a) 2013



(b) 2014



(c) 2017



(d) 2018

Figure 6: Comparative annual rotary data for Axis 75 & 55 kHz ADCP, in 2013, 2014, 2017, and 2018. Rotary spectra are for the CW and CCW velocity data, at an upper depth of -99 m and lower depth of -330 m. PSD were processed using mean-removed and cleaned velocity data (see above), optimised Welch FFT parameters, and a custom process based on Thomson and Gonella, as described above.

1.4 Spectrograms

Spectrograms were generated using similar methods and parameters as for PSD, and 'whitened' for visual clarity (multiplying spectrogram output by frequency squared). Plots are truncated to show relevant frequency bands for analysis, and primary constituents are indicated with dashed lines.

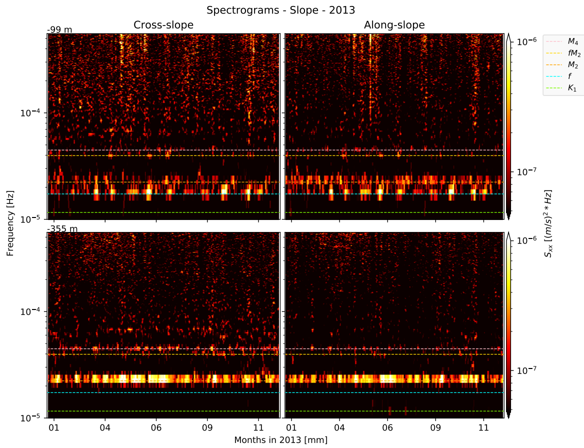
Upper Slope 75 kHz ADCP

- Along-slope spectrograms at -99 m indicate common pulses of annual activity in higher frequencies: notable activity through the winter/spring and fall, with diminished activity through the summer possibly due to the absence of winter storms. These pulses are less prominent at -330 m, suggesting forcing by weather.
- Though these pulses are more pronounced in the along-slope direction, there is more consistent activity at higher frequencies in the cross-slope direction, perhaps due to turbulent motion as water crosses from deep to shallow waters? It is also possible that notable along-slope currents are intensifying the along-slope pulses.
- There are notable short-term events that are likely associated with passing storms, with time-scales of a few days to a week, evident in the seasonal data.
- At -99 m, f and $K1$ seem to play more of a role than deeper down.
- All frequencies seem to have a common pulse in the late spring, perhaps related to the annual switch in regional mean currents.
- There is a notable lull in activity through June/July, possibly due to the absence of winter storms.
- At -330m $K1$ and f seem to play a weaker role as depth increases.

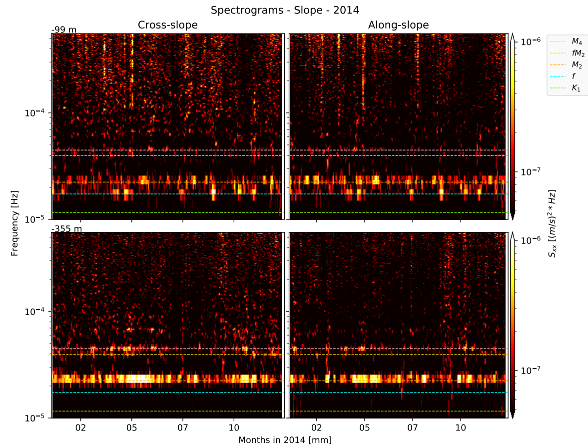
Axis 75 & 55 kHz ADCP

- In 2013 and 2014, some frequency banding in the high frequencies corresponds with notable spikes in the PSD data, but are so consistent that they are likely an instrument issue. Analysis will be primarly for 2017 and 2018 (for now).
- The -393 m spectrograms show an apparent pulse in the winter and fall, with similar variance for both cross- and along-slope.
- The -913 m spectrograms show consistent activity in the high frequency range for both directions, and more tidal and inertial activity in the along-slope direction. The proximity to the bottom of the canyon likely instigates more activity.

- ### 1.4.1 Annual spectrograms



(a) 2013



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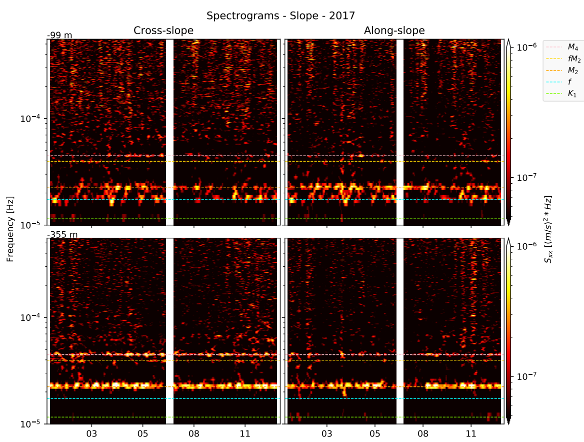

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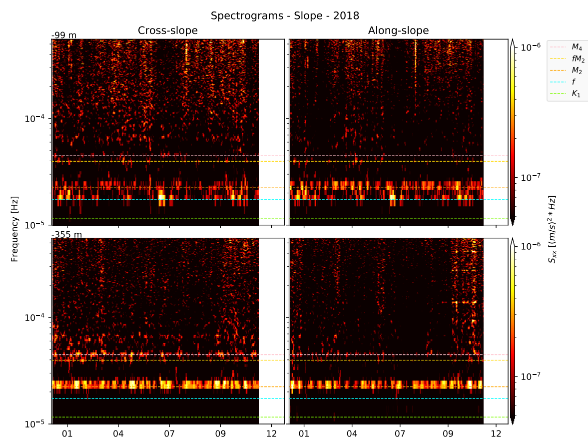
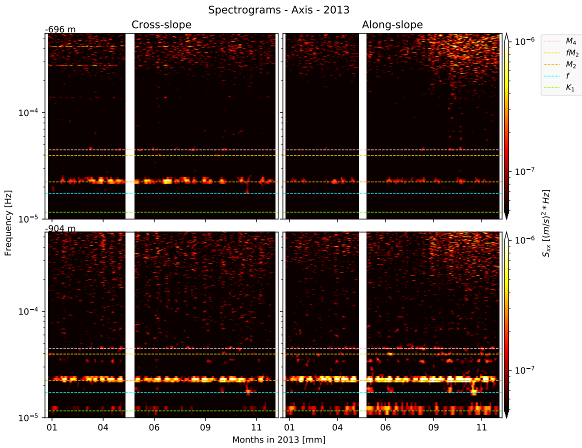
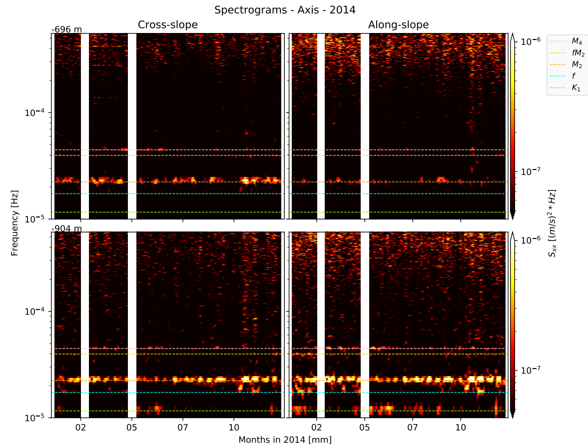


(d) 2018

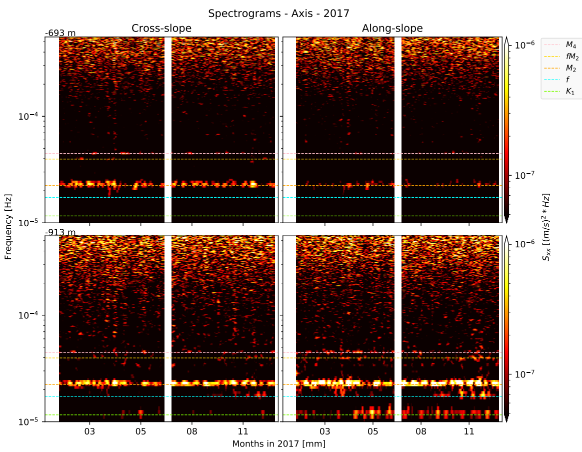
Figure 7: Whitened, comparative spectrogram data for Upper Slope 75 kHz ADCP, at -99 and -330 metres depth, in 2013, 2014, 2017, and 2018. Spectrograms are for the cross- (upper) and along-slope (lower) velocity data. Spectrograms were processed using mean-removed and cleaned velocity data (see above), optimised Welch FFT parameters, and whitened for visual clarity.



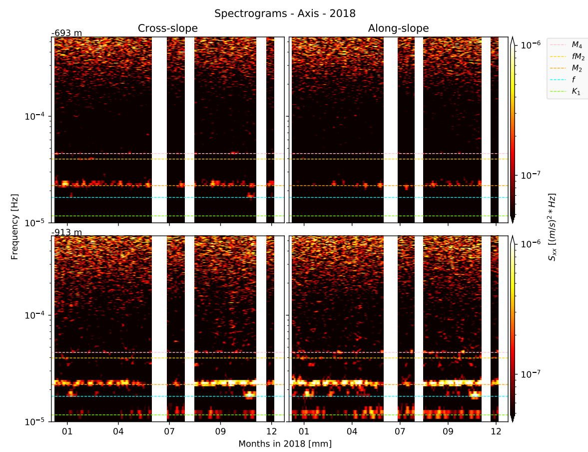
(a) 2013



(b) 2014



(c) 2017



(d) 2018

Figure 8: Whitened, comparative spectrogram data for Axis 75 & 55 kHz ADCP, at -99 and -330 metres depth, in 2013, 2014, 2017, and 2018. Spectrograms are for the cross- (upper) and along-slope (lower) velocity data. Spectrograms were processed using mean-removed and cleaned velocity data (see above), optimised Welch FFT parameters, and whitened for visual clarity.

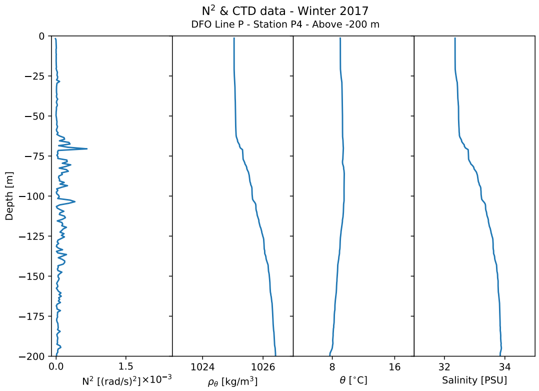
1.5 Buoyancy and CTD

Climatology data from annual Line P cruises allow for buoyancy and density calculations through depth, which can provide insight into the structure of the water column. CTD data were obtained from La Perouse/Line P cruises. Barkley Canyon is centred at approximately 48.33°N 126.03°W, so Rosette (deep) CTD casts from Station P4 are closest (approximately 48.39°N 126.39°W); a distance of about 27 km. Winter CTD casts were within January/February, and summer casts were within August/September. The Seawater package was used to calculate density, $\rho(z)$, and the Brünt-Väisälä Frequency squared ($N^2(z)$), based on the UNESCO 1983 (EOS 80) polynomial, at the mid-depths from the equation:

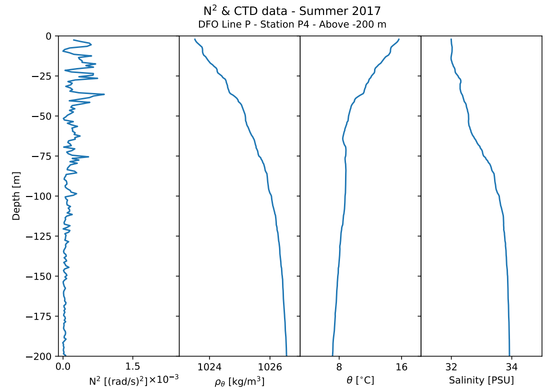
$$N^2 = \frac{-g}{\sigma_\theta}\frac{d\sigma_\theta}{dz}$$

where σ_θ is the density based on potential temperature values. These N^2 values were then applied to a modified Python GM toolbox to generate a GM spectrum based on local climatology.

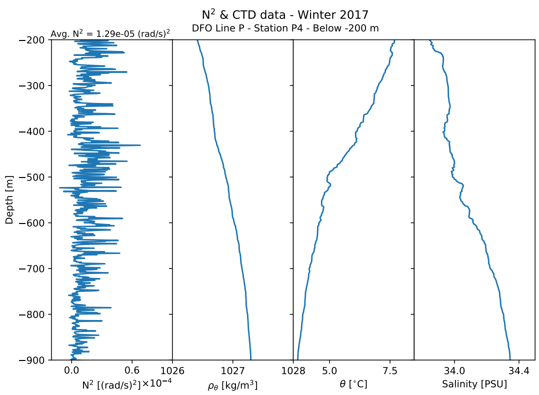
- In the upper 200 m, there is only slight variation to the N^2, density, temperature, and salinity profiles, with greater variation in the summer months (depth and slope of the pycnocline).
- Below 200 m there is even less variation, indicating that internal tides don't change much. Through the decade, lower depth N^2 is fairly static around 1.1e-5 (rad/s)^2, which gives an N value of around 3.3e-3 rad/s.
- Since the ADCP data does not show much above 200 m, no WKB scaling is necessary.



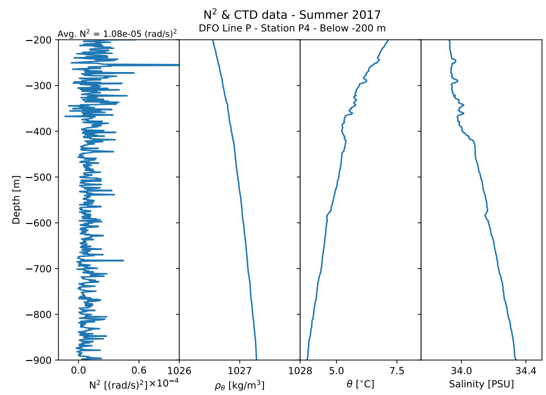
(a) Upper Winter



(b) Upper Summer



(c) Lower Winter



(d) Lower Summer

Figure 9: Seasonal N^2 and CTD data for Station P4 of Line P, collected by the DFO in 2017. The top row are upper depth plots (above -200 m), and the bottom row lower depth plots (below -200 m). Each plot shows N^2, density, temperature, and salinity, in order.

1.6 Vertical velocities

More will be added to this section as analysis continues.

Vertical velocity data were put through the same analysis process as the horizontal data, with adjustments to account for being unidirectional and of smaller magnitude.

Upper Slope 75 kHz ADCP

- Vertical velocity data is fairly consistent through the years and seasons, and has little to note beyond some seasonal variation that aligns with the horizontal observations already mentioned, and a resonance or harmonic effect near the surface that is possibly due to the presence of biological interference. However, very little delving has been done, and more analysis could be conducted.

Axis 75 & 55 kHz ADCP

- Vertical mean current velocity data shows sinking water at upper depths in the winter and spring, and rising water at upper depths the rest of the year.
- Lower depths show mean currents as consistently sinking, though these velocity values are very small.

1.7 Data management and processing

- Datasets were obtained from ONC OCeans 2.0 in NetCDF format, at an averaged sampling rate of 15 minutes. This was determined adequate for the analysis intended, to balance file size versus the 2-second interval data that is available. Datasets had different depth intervals for different periods, so each set was combined via XArray processing that interpolated subsequent dataset depths onto the depths of the original dataset for each series. This ensured consistent depths to avoid processing issues during analysis.

  Averaged data was compared with raw data to ensure the preservation of variance and key features such as noise floors.

  Noise floors were calculated using the per-ping standard deviation as given by the manufacturer, comparing this variance with the integral of the white noise spectrum for a given frequency range to find its steady amplitude.

  Data quality threshold depths were determined from a process that checks 20-ping bins versus depth, for both correlation strength and echo intensity, per beam. The average depths for each beam are compared and averaged to estimate a threshold depth above which data quality is reduced, and should be ignored.

  Bathymetry were generated from NOAA depth data for the region, and scaled and contoured to reflect the best visual quality for interpretation.